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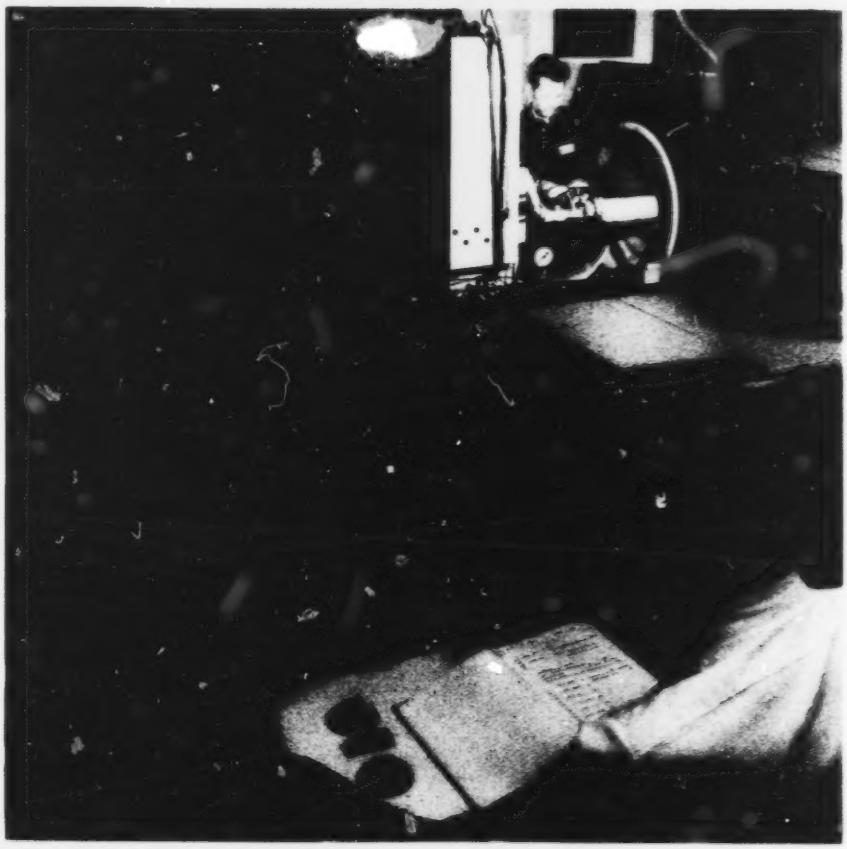
Oil Sands and Hydrocarbon Recovery Research at the Alberta Research Council

M.P. duPlessis



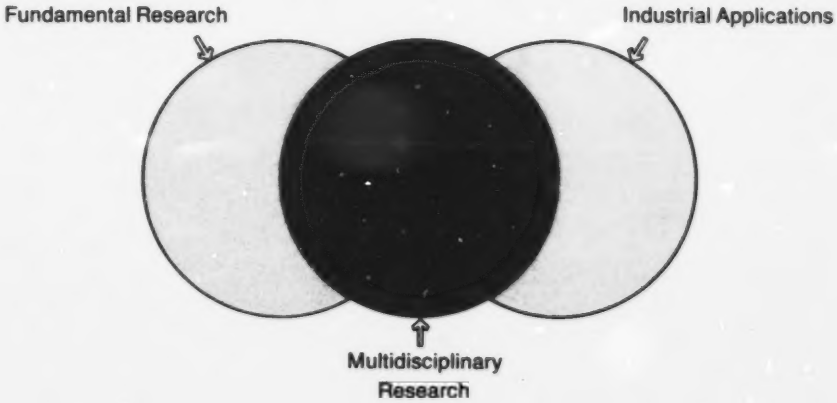
ALBERTA RESEARCH COUNCIL

Oil Sands and Hydrocarbon Recovery Department

Abstract

The mission of the Alberta Research Council is to aid the economic development of the Province. Exploitation of Alberta's vast hydrocarbon resources is central to this mission. A patent issued to Dr. Karl Clark of the Research Council in 1928 formed the basis for the hot water extraction processes used in present commercial operations for mined oil sands. In 1971 the research focus shifted to in situ recovery of oil from the more plentiful and deeper deposits and on ways to make these techniques more economical and more productive. A comprehensive multidisciplinary research program with the associated facilities and infrastructure has been developed. The program augments and complements related work and expertise in universities and industry, and consequently effectively aids transfer of research concepts to field applications. Where required, projects can draw on the Research Council's capabilities in technical and economic evaluations, expert systems, artificial intelligence, advanced materials and biotechnology to meet the needs of particular industrial applications.

Having the scientific and technical expertise and infrastructure the Research Council provides cost effective research to industry and government in a variety of ways including contracts, joint ventures and multi-client studies.



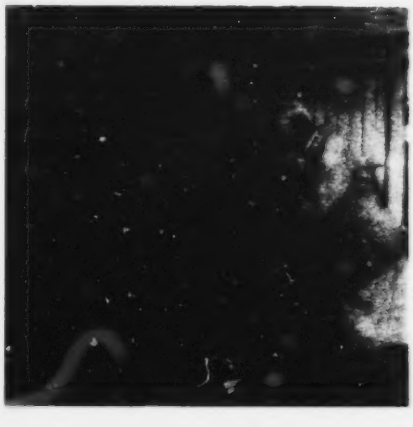
The Alberta Research Council's multidisciplinary research provides an interface between fundamental and applied industrial research, complements expertise in universities and industry, aids technology transfer and problem solving, and is conducted in close collaboration with clients from government and industry.

Introduction

Since its founding in 1921, the Alberta Research Council has been engaged in oil sands research. An early employee, Dr. Karl Clark, received a patent in 1928 on a hot water process for extracting bitumen from mined oil sands, which later formed the basis of the extraction processes used in the commercial operations of Suncor Inc. and Syncrude Canada Ltd. at Fort McMurray. Prior to 1971, research concentrated on the physical and chemical properties of oil sands and on separation of bitumen from mined oil sands.

Over 90 percent of Alberta's oil sands deposits, however, cannot be economically processed by mining methods. In 1971 the research focus shifted to in situ recovery of oil sands and heavy oil. In situ recovery of heavy oil involves heating the reservoir by combusting part of the oil with injected air or oxygen, or by injecting steam or hot water into the formation and driving the liberated heated oil towards a production well as shown in figure 2. In the so called huff and puff mode, the same well is used first to inject steam (huff) and then to produce (puff) the oil. The objective of the Alberta Research Council program is to develop a better understanding of these processes and to investigate ways of making field operations more economical and more productive.

The program which has evolved at the Research Council over the last 16 years comprises coordinated multidisciplinary investigations into basic mechanisms, physicochemical parameters, geochemistry and geology. It involves experimentation in high pressure and temperature physical simulators and mathematical modelling of thermal recovery processes. Figure 3 depicts the interactions among these activities, all of which are directed towards guiding, supporting and optimizing field operations. The type of work conducted in the program bridges the interface between fundamental research normally associated with universities, and technology development carried out by industry. The Research Council program augments and complements related work and expertise at universities and industry, and consequently effectively aids the transfer of research concepts to field application. Although initially directed mainly to in situ recovery of oil sands and heavy oil, the work has become applicable to specialized areas in hot water recovery of bitumen from mined oil sands, enhanced recovery of conventional oil and to related production and environmental problems.



◀ **Figure 1.** Dr. Karl Clark developed the patented hot water process for extracting bitumen from mined oil sands in the late 1920s at the Alberta Research Council.

◀ **Figure 2.** In situ steam drive process. An objective of the Research Council program is to develop a better understanding of in situ processes and to investigate ways of making field operations more productive and less costly.

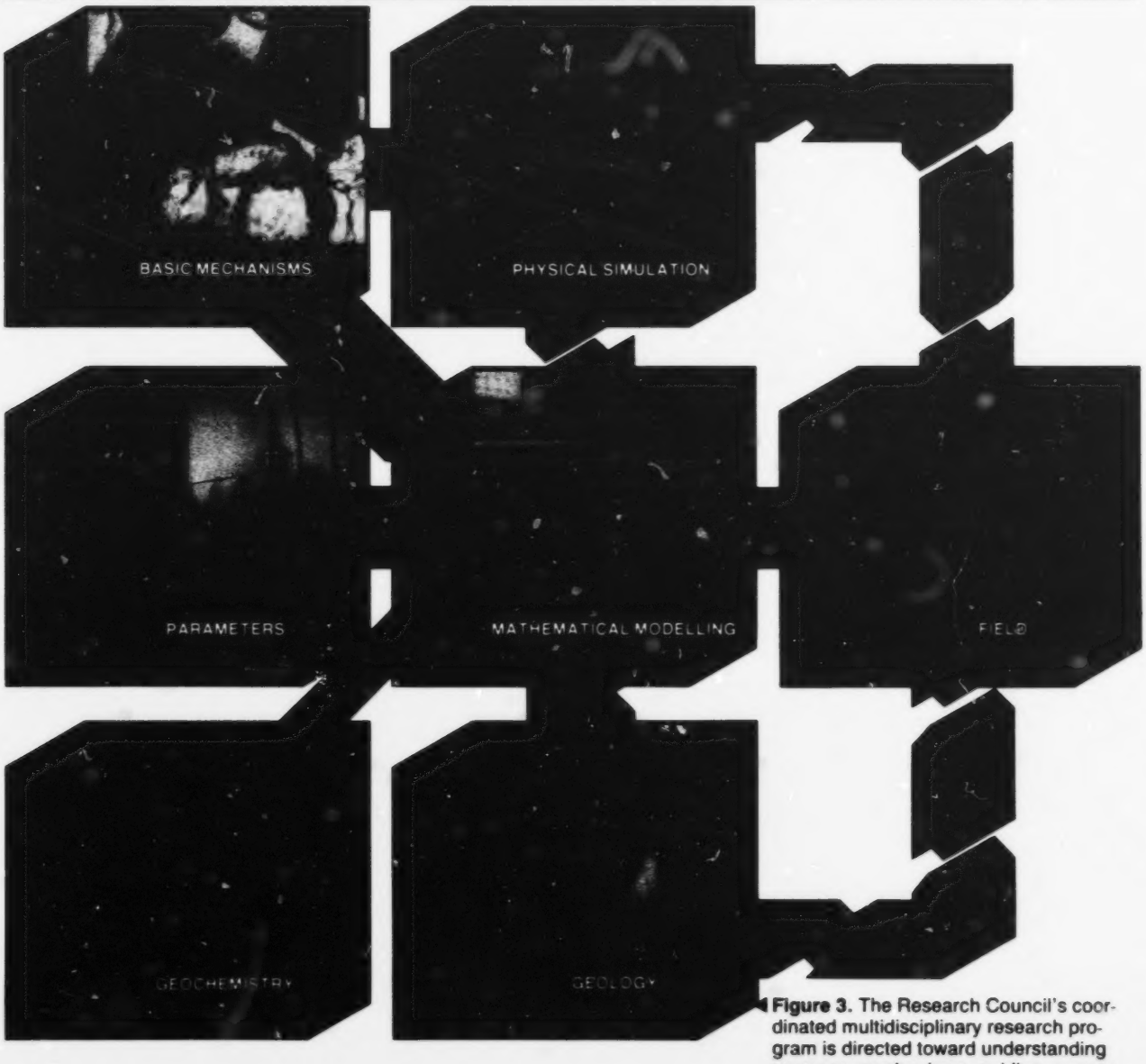


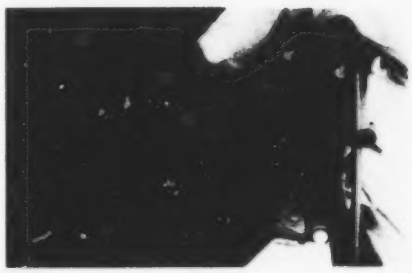
Figure 3. The Research Council's coordinated multidisciplinary research program is directed toward understanding recovery mechanisms, guiding, supporting and optimizing field operations.

Basic Mechanisms

Development of in situ technology requires an understanding of the mechanisms governing the liberation and displacement of oil from the mineral matrix and the subsequent flow of multicomponent oil-water-gas mixtures through porous media.

Colloid Chemistry and Interfacial Phenomena

It has been recognized by several investigators that the double layer interaction between charged interfaces (oil/water and mineral/water) plays an important role in many aspects of oil recovery (figure 4). A theoretical model was developed at the Research Council for the separation of oil from sand aggregates immersed in aqueous media (1,2). The model describes the displacement mechanism in terms of capillary forces at the oil/aqueous interface, the viscous drag of the oil and the stability of the aqueous film on the sand surfaces. In addition to identifying conditions conducive to mobilization of oil in a reservoir, the model successfully explains most of the observed effects of pH, mono- and divalent cations on the hot water separation of mined oil sands (3). Stability field diagrams of the type shown in figure 4 (below) were developed to predict maximum recoveries achievable for various grades of oil sands. This work is being extended to the prediction of changes in wettability of heavy and light oil reservoirs (4), the settling characteristics of solids in oil sand tailings and the properties of clay suspensions (5).



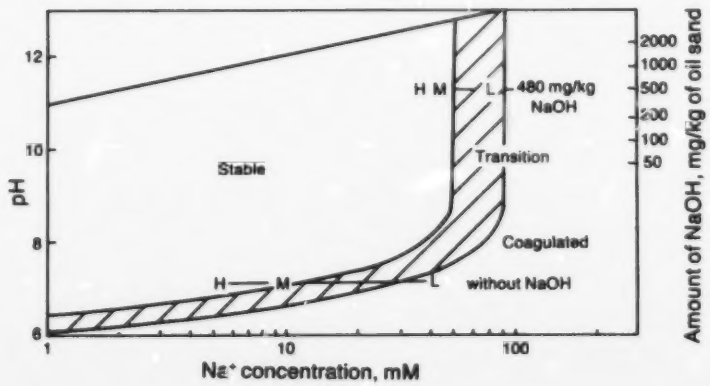
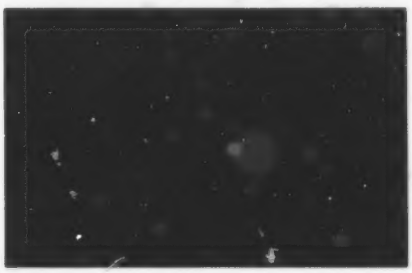


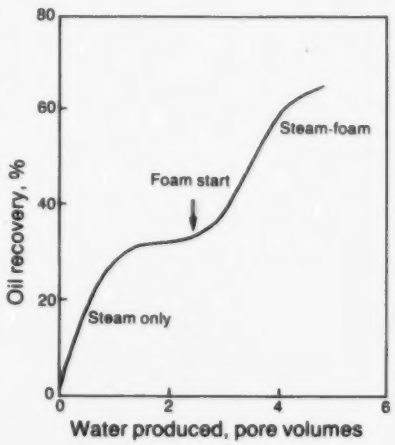
Figure 4. Oil sands micro model (top). The stability of the water film on sand surfaces plays an important role in oil liberation and recovery.
A novel Laser Doppler apparatus (center) is used to measure the surface properties of oil suspensions more accurately and quickly than possible before.
Below. Theoretically calculated stability diagram for fines particles as a function of pH and Na^+ concentration predicts optimum separation conditions for different grades of oil sands: High grade (H), Medium (M), and Low grade (L).

Surfactants and Foams

Surfactants reduce the interfacial forces between oil and water and thereby facilitate the oil flow rate through the pores. Under certain conditions, surfactants can also form foams that block the flow of steam through regions of the reservoir already depleted, diverting the steam to regions still rich in oil (figure 5a). Researchers are studying the physical and chemical properties of surfactants at elevated temperatures and pressures, their interfacial behavior, and their effectiveness as additives to steam based processes operating in a drive mode from an injection well to a producing well (figure 5b) (6). The work is now being extended to investigate the effectiveness of foams in a single well cyclic huff and puff mode (figure 6),(7). A mechanistic model has been developed which describes the foaming behavior of alkyl-aryl sulfonate surfactants in multiphase flows through a porous medium. The mechanistic model has been incorporated into a large mathematical model which includes surfactant adsorption/desorption, thermal degradation, partitioning between oil and water phases and mobility changes as implicit functions of superficial gas velocities, fluid saturations, surfactant type and concentration (8).



◀ **Figure 5a.** Under certain conditions, surfactants form foams which block steam flow through depleted areas, thus improv ing areal sweep and oil recovery.



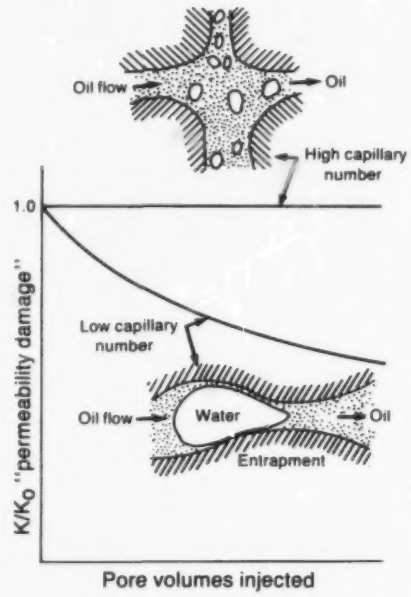
◀ **Figure 5b.** Experimental recovery curve for steam drive process using Cold Lake core shows beneficial effect of foam.

◀ **Figure 6.** Experimentation and modelling show that foaming can be induced in a cyclic huff and puff process and that recovery increases when foam is introduced.

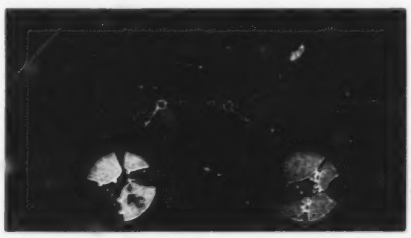
Emulsions and Fines Transport

Conditions prevalent in thermal heavy oil recovery processes often favor formation of water-in-oil emulsions with water contents as high as 50 percent. It is well known that the measured viscosity increases dramatically with increasing content of emulsified water. Researchers are studying the formation and breaking of emulsions, their stability and flow behavior in porous media (figure 7).

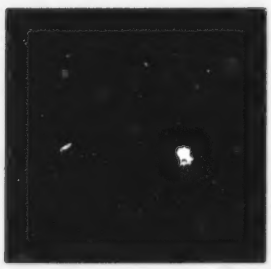
Under certain reservoir conditions, fine solids such as clays can be mobilized, transported, and then deposited at pore throats, where they can reduce the permeability of the reservoir. Fines, initially adhering to sand grain surfaces at conditions of attractive colloidal forces, become mobile when the hydrodynamic force exceeds the attractive force between the fines and grain surfaces (figure 8a). Deposition and permeability reduction occur at locations where the force balance is reversed. The mechanistic model, based on colloidal, hydrodynamic and filtration theories has been verified with experiments conducted with kaolinite-NaCl suspensions (figure 8b). At low electrolyte concentrations, permeability reduction is less than the severe reduction that occurs at high concentrations when colloidal forces are attractive. The mechanistic fines transport model has been incorporated into the large Research Council mathematical model (9) which can predict the observed effects of water salinity on permeability damage in field operations.



◀ **Figure 7.** The diagram shows the effect of capillary number (ratio of viscous/capillary forces) on permeability reduction when emulsified water is either trapped or dispersed.



◀ **Figure 8a.** Mechanisms of permeability reduction due to fines transport.



◀ **Figure 8b** Effect of electrolyte concentration on fines deposition and permeability reduction.

Multiphase Flows and Computed Tomography

The inability to see what is happening inside porous media, particularly how fluid flow patterns and saturations change during displacement processes, prompted development of a number of nonintrusive X-ray techniques (10). The most advanced is medical brainscanning computed tomography (CT) which has been adapted at the Research Council for high pressure/ temperature dynamic core flood experimentation (figure 9). By moving the core axially through the scanning head, complete three-dimensional visualization and measurement of fluid saturations are obtained during a core flood experiment (figure 10). Figure 11 is a CT image at one axial location showing how the hot water tends to "underride" and "finger" through the more viscous oil contributing to early water breakthrough and poor oil recovery in a water flood process. Such experiments are particularly useful to study the effectiveness of different additives or operating strategies to increase conformance (areal sweep efficiency) and oil recovery.

In a recent joint venture with a seismic exploration company, CT is being combined with acoustic impedance measurements in cores, to determine whether oil reservoir miscible displacement fronts can be monitored by high resolution three-dimensional seismic methods (11).

◀ **Figure 9.** Computed tomography apparatus for dynamic core flood experimentation.

◀ **Figure 10.** Schematic of CT imaging at different axial locations during a water flood experiment.

Figure 11. CT image of one axial location gives water and oil saturations at 1 mm by 1 mm resolution over the entire cross section during a water flood experiment. ▼

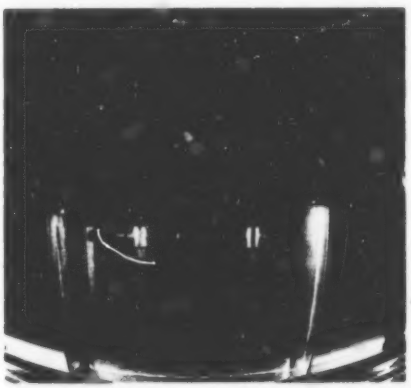
Parameters

The values of various physical properties are needed for mechanistic and process models. Important parameters are viscosity and equilibrium properties such as gas solubilities, phase behavior and pressure-volume-temperature (PVT) relationships. Other parameters are mass transfer coefficients of additives, heat transfer, diffusivity and capillary pressure.

To improve oil recovery, the effect of various additives such as CO_2, CH_4, C_2H_6, and naphtha are being investigated. Existing data and models of such multicomponent and multiphase mixtures with heavy oil at high temperatures and pressures are inadequate. Accurate measurement of these properties is often difficult because of the long equilibrium times required, phase separation problems, and the viscous nature of heavy oils. In many cases, special equipment and measurement techniques had to be developed to achieve the required accuracy. Several high temperature and pressure multiphase relative permeability test stations have been developed (figure 12).

Rheology

A unique high temperature and pressure viscometer that can operate at known, variable subsaturation gas concentrations was developed (figure 13). A reliable equation has been derived for predicting the effects of temperature, pressure and additive concentration on the viscosity of bitumen (12). The viscometer is also suitable for rheological studies of water-in-oil emulsions. Rheological studies are in progress to determine whether heavy oil undergoes in situ thermal degradation (visbreaking) during steam extraction.



◀ **Figure 12.** High pressure and temperature relative permeability apparatus for two phase bitumen-steam flows.

◀ **Figure 13.** This unique high temperature and pressure viscometer can operate at known variable subsaturation gas concentrations.

Vapor-Liquid Equilibrium Properties

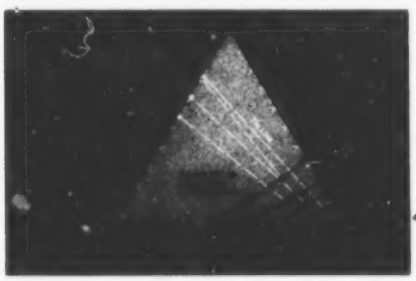
Vapor-liquid equilibrium (VLE) properties are needed for both binary and ternary heavy oil-gas mixtures (figure 14). The common practice is to predict ternary properties from binary data and to treat bitumen as one "pseudo-component". The accuracy of these practices is being evaluated. VLE measurements are conducted in a modified rocking equilibrium cell capable of operating at 14 MPa and 150°C. A unique feature of this cell is that both vapor and liquid volumes are measured accurately by a piston which maintains a constant pressure as samples are withdrawn. Such experiments are time consuming and a new visual cell apparatus is being developed to reduce time. Predictive methods are necessary for computational purposes. The Peng-Robinson (PR) and the modified Soave-Redlich-Kwong (MSRK) equations of state have been used for this purpose. These equations require characterization parameters for the oil and binary interaction coefficients for the mixtures. Some of these values have been determined to improve predictions for bitumen-gas systems (13) (figure 15).

Multiphase Heat Transfer Studies

An advanced heat transfer cell was developed for studying multiphase conduction and convection heat transfer in porous media. The work focuses on the transition zone between the hot steam zone and the cold immobile bitumen zone (14). The purpose is to understand the mechanisms of heat transfer so that techniques can be devised for accelerating heat and mass transfer into the formation. This work, carried out as part of a Ph.D. program, is an example of complementary interaction between the Alberta Research Council and the University of Alberta.

Capillarity

It is estimated that capillary forces and bypassing of rich oil regions account for the fact that 30 to 60 percent of the oil in reservoirs is not recovered by water injection. Part of the residual oil is trapped in pores by capillary forces. The most important parameters characterizing capillary forces are interfacial tension, contact angle and capillary pressure. These parameters are affected by surfactant properties, the chemical composition of the aqueous phase, the nature of the mineral surface and by temperature. Saturation hysteresis occurs when an initially water-saturated porous medium is taken through a drainage-imbibition-drainage cycle. The hysteresis between drainage and imbibition effects oil recovery particularly in cyclic steam operations, and the challenge is to develop reliable models from laboratory experiments (15).



◀ **Figure 14.** Vapor-liquid equilibrium diagram for a ternary bitumen-carbon dioxide-methane mixture.

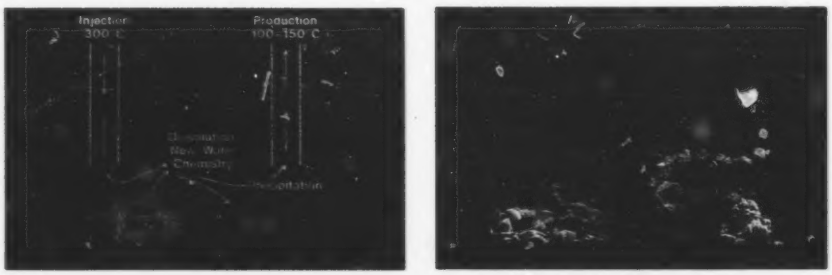
◀ **Figure 15.** Comparison of measured and predicted liquid densities for carbon dioxide-Athabasca bitumen mixtures at 100°C.

Geochemistry

Hot aqueous reservoir fluids can react with reservoir minerals and fluids resulting in dissolution and re-precipitation of existing minerals as well as formation of new minerals (figure 16 left). As such transformations can change and damage reservoirs, it is important to have a detailed understanding of geochemical reactions. A computer program, SOLMNEQF, has been developed which uses thermodynamic data and measured water compositions to calculate the molalities and activities of the aqueous ions at reservoir conditions (16). SOLMNEQF also calculates injection water-formation water incompatibilities, partioning of volatile components between oil, gas and water and the saturation index of mineral phases. To facilitate interpretation of the water-rock-oil interactions, the aqueous ion concentrations are plotted on pressure-temperature-composition-log activity diagrams (17,18).

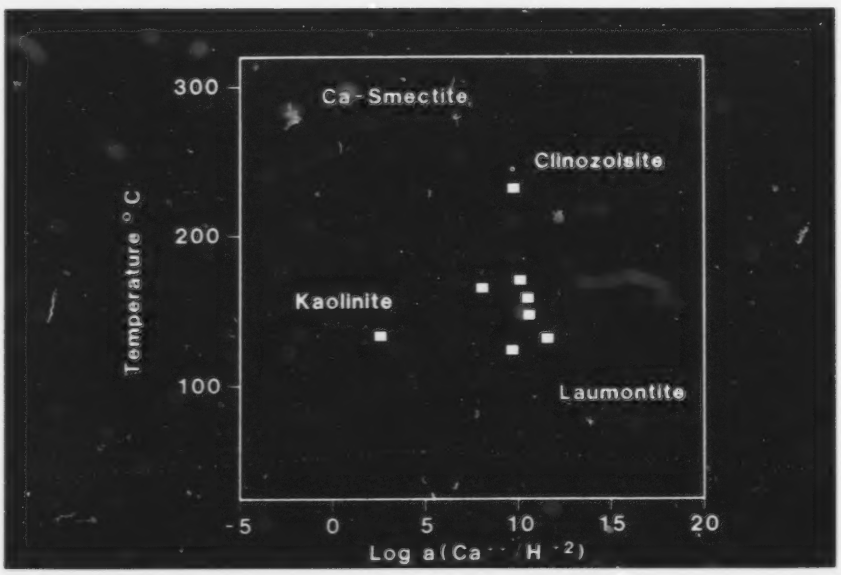
Figure 17 shows the stability of three problem mineral phases encountered in enhanced oil recovery, namely kaolinite, a smectite and a zeolite (Laumontite). The axes are temperature versus log activity $Ca^{++}/(H^{+})^{2}$. Each of the square symbols plotted on the diagram represents one production water analysis from the field. Most of the points cluster around the Smectite/Laumontite boundary, indicating a potentially serious plugging problem from the growth of smectite clays in this reservoir.

The above example illustrates that the results of fundamental research on geochemical reactions are directly applicable to field problems.



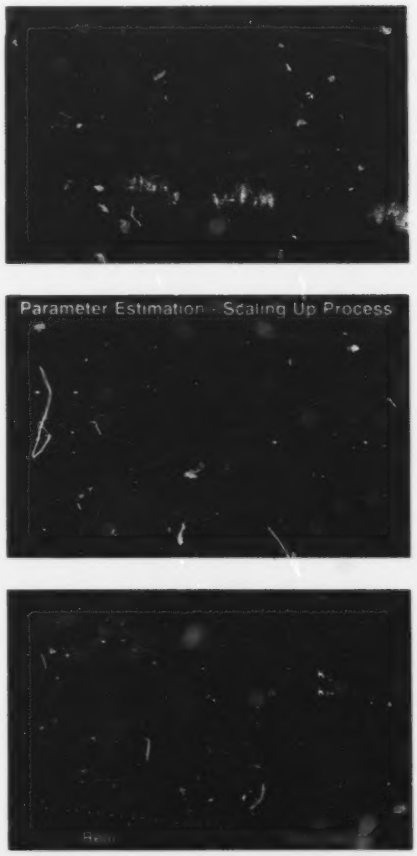
▲ **Figure 16.** Schematic of geochemical reactions (left). Photomicrograph of reservoir minerals (right) shows changes to mineral structures resulting from dissolution and precipitation reactions when high pH wet steam at 250°C is injected into a core for several days.

▼ **Figure 17.** Temperature-composition-log-activity diagram for mineral phases encountered in an enhanced oil recovery operation. Square symbols represent production water analyses taken at different times from the field.



Geology

The Research Council's current oil sands geology research has two major technical thrusts: regional (deposit-scale) resource characterization investigations of the still undocumented portions of major deposits and detailed (reservoir-scale) interdisciplinary investigations of the critical geological parameters which affect resource recoverability (19). The regional work provides documentation and assessment of the resource in terms of stratigraphic and structural settings, reservoir boundaries, predictive depositional models, and an outline of reservoir fluid distribution expressed as oil, water and gas saturations. The more detailed studies are intended to determine effective means of integrating geological and petrophysical data into numerical models. The challenge is to model geological features having scales from microscopic (pore-scale) to gigascopic (formation-scale) with associated heterogeneities, and to incorporate these into numerical extraction models at a grid block scale. A research program is underway to model the occurrence, shape and orientation of impervious shale and silt clasts, and to provide suitable grid block scale equivalent values for porosity, vertical and horizontal permeability (20). The general approach taken in this program could also be applicable to other reservoir heterogeneities such as fracture systems or the heterogeneous pore systems.



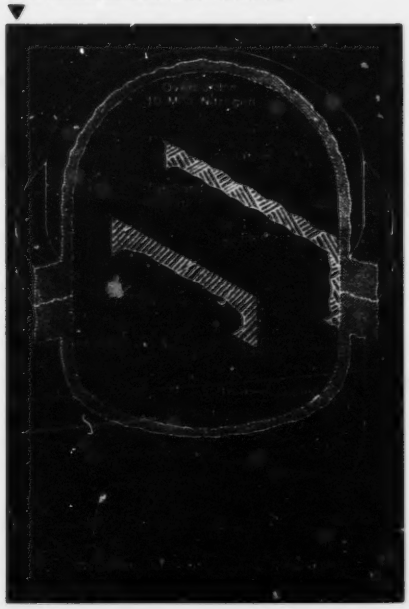
◀ **Figure 18.** Structure contours beneath the McMurray Formation-Northern Athabasca deposit (top) showing formation heterogeneities. The challenge is to model geological features having scales from microscopic to gigascopic (middle, bottom).

Physical Simulation and Scaled Models

Experimental investigations are conducted in a range of high pressure and temperature simulators ranging from core size to a large 150 cm diameter simulator requiring some 5000 kg of test sample (figure 19). The large simulators can be configured to simulate injection and production strategies in one, two or three dimensions (figure 20). Whenever practical, scoping studies are conducted on core-size simulators. Large simulators are then used to evaluate selected process concepts. Experimental results are compared with mathematical model predictions to verify the models, to increase understanding of dominant mechanisms, and thereby guide further experimentation and ultimately increase the reliability of field predictions.

Figure 19. Examples of different physical simulator configurations (top). The 45 cm simulator is shown in the vertical configuration (bottom).

Figure 20. The 150 cm simulator with a two dimensional test element.



Steam Additive Processes

To make in situ steam-based processes more economical and more productive, extensive experimentation and analyses were conducted for steam only processes, steam and single additive processes and steam and dual additive processes. It was found that operating strategy plays an important role in optimizing recovery. In a typical investigation conducted in the 150 cm simulator, the effect of CO_2 was evaluated for four strategies, (i) CO_2 presoak followed by steam injection, (ii) steam-CO_2 coinjection, (iii) steam injection followed by CO_2 slug injection after a draw down and (iv) steam, CO_2 and solvent coinjection (21). The data were also analyzed

using the multicomponent numerical simulator which incorporates equation of state predictions and other properties for the particular multicomponent mixtures. Some interesting conclusions from this investigation were that a) all steam additive combinations gave improved recoveries over a steam only process, b) viscosity reduction due to dissolved CO_2 was the dominant mechanism for improved recovery in all cases even with CO_2 slug injection using 95 percent less CO_2 than coinjection, and c) in the presoak case the gas drive caused by release of dissolved CO_2 further improved recovery during the drawdown phase of the first pressure cycle. In subsequent cycles, viscosity reduction was the dominant mechanism. This investigation is an example of how laboratory experimentation combined with mathematical modelling enhances understanding and can aid planning of field operating strategies.

Horizontal Wells

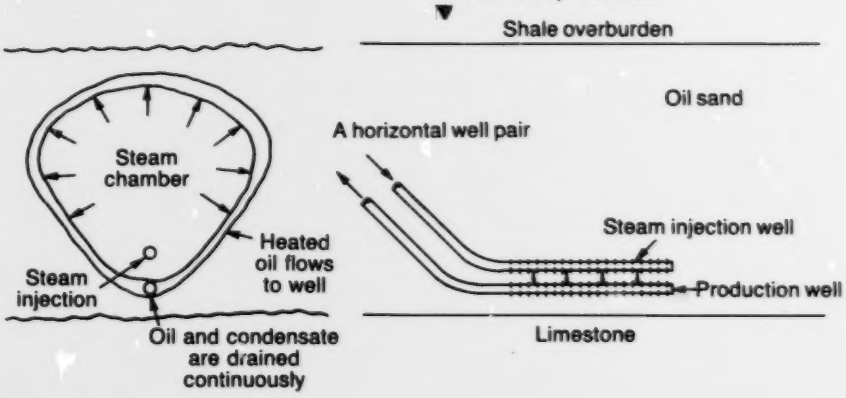
Since 1979, extensive work has been carried out under contract for Texaco Canada Resources Limited, which has resulted in some 36 patented process concepts. To overcome the dominant influence of reservoir heterogeneities on production, increased effort was devoted to investigating the use of horizontal wells, and to study the effects of communication between injection and production wells (figure 21). An extensive laboratory investigation into the parameters which influence production of bitumen from horizontal wells was carried out (22).

Production Strategy

More detailed investigations are now being conducted to determine the effect of steam quality and injection rate on the rate of heat penetration and oil recovery. The use of novel steam additives to improve recovery is being investigated. Foams, and more recently microorganisms, are being investigated as blocking agents for conformance control. Emphasis is being placed on developing production strategies that yield maximum profit particularly during the initial years of operation (figure 22). These studies use coupled production and economic models described under Technical and Economic Evaluation.

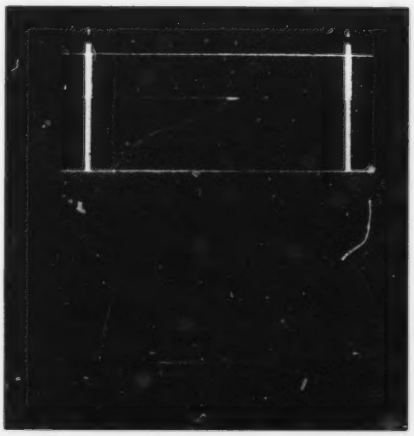
◀ **Figure 21.** The 100 cm simulator has been used successfully for laboratory investigations of various in situ recovery processes.

Figure 22. Different horizontal well production schemes are being investigated. Numerical reservoir and economic models show potential advantages over vertical well processes.



Scaled Experiments

Scaling is a technique used to design laboratory experiments yielding results which can be related directly to field predictions. Scaling criteria for different steam recovery processes are being investigated (23). The approach taken is to scale down a hypothetical reservoir in order to design a series of experiments in two laboratory models: a large model and a small model (figure 23a). The dimensionless results from the two models are compared and used to evaluate different theoretically derived scaling criteria. One approach uses field porous media and field pressure conditions but relaxes gravitational effects. This approach was found to give good predictions of energy distributions, production rates, steam zone volumes, produced steam qualities and steam breakthroughs. Figure 23b shows the good agreement obtained for steam quality and steam breakthrough with experimental data from the large and the small laboratory models. Other parameters are now being investigated. This work is being carried out as part of a Ph.D. program at the University of Alberta.



◀ **Figure 23a.** Scaling of a steam flooding process. Hypothetical reservoir (top) is scaled down. Laboratory size models (bottom) are used to evaluate different scaling criteria.

◀ **Figure 23b.** Produced steam quality and the time required for steam breakthrough to occur are used to compare the validity of different scaling criteria.

Mathematical Modelling

A six component fully implicit mathematical model capable of simulating both laboratory and field scale tests has been developed. The model incorporates water, oil, two additive components, silica and a tracer (21,24,25). Energy and mass of all components are conserved. Continuously differentiable functions are used in all correlations. The model can predict silica transport based on experimental silica kinetic measurements rather than equilibrium calculations. Multipoint differencing schemes are used in various geometries based on an extension of the harmonic scheme of Coats and Modine (26). To account for heat loss from the formation, various models are used including a multidimensional heat loss model. These equations are solved fully implicitly with the equations in the active grid.

Solubility of all components in all phases is allowed, these being the oil phase, the aqueous phase and the gaseous phase. Noncondensible gas calculations are also included. Silica and the tracer are allowed to dissolve only in the water phase. When a component other than oil is transported into a grid block, it distributes itself among the gas, liquid and bitumen as if the grid block was at equilibrium. Equilibrium K-values govern the process. Solubilities and K-value correlations are obtained from the Peng-Robinson equation of state. The calculation of bitumen viscosity as a function of temperature, pressure and mole fraction of additives is based on experimentally derived correlations. Relative permeability curves are based on measured values.

Foam and Fines Transport Models

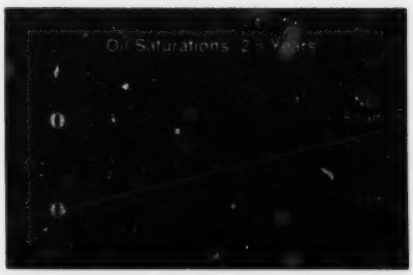
Recently, two additional features have been incorporated in the model: foam transport and fines transport as described in the previous section on Basic Mechanisms (7,8). Figure 24 depicts the results from a simulated test in a typical oil reservoir using a foaming agent. Frontal displacement of oil is obtained which clearly demonstrates the beneficial effect of the foam in this reservoir.

Horizontal Well, Wellbore and Geology Models

Increasing interest in the use of slotted horizontal injection and production wells to improve steam distribution and oil recovery has prompted the development of a complete numerical reservoir/pipe model which includes the complex distribution of flow, pressure and heat along a slotted pipe, and the heat and mass transfer in the reservoir. This model is operational and is being used to design new horizontal well systems and to assess the performance of wells already in operation.

In the future, geological features will be added to the reservoir model based on the work described in the previous section on Geology.

These examples show that mathematical modelling is the core activity which captures and combines knowledge gained from all research disciplines. The usefulness of the models for guiding both experimentation and field trials increases as research progresses and new knowledge is incorporated in the models.



◀**Figure 24.** Numerical simulation of a reservoir in the Bodo field shows how foam affects the oil saturations and the displacement fronts between the injection well (I) and the production zone (P).

Production Research

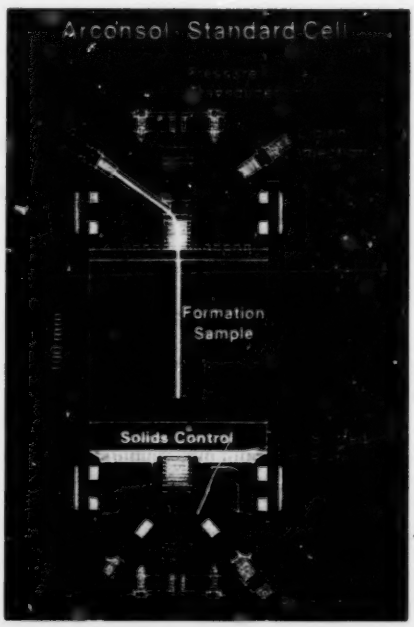
Low profit margins caused by low and unstable oil prices have increased the importance of production efficiency and costs of commercial operations. Projects undertaken in this area include downhole sand control filters, sand deposition and fluidization in horizontal pipes, multiphase/multicomponent pipe flow and measurement systems, multiphase pump performance studies, and corrosion and scaling studies.

Sand Control

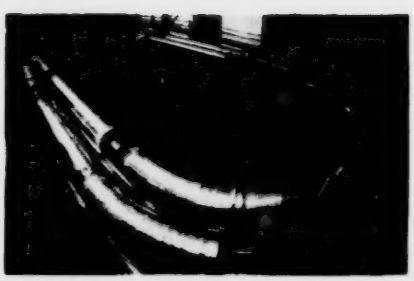
The Research Council has developed several special purpose test facilities to investigate sand control problems including a solids control test apparatus to evaluate solids control devices (figure 25) and a solids entrainment test loop to study deposition and removal of solids in horizontal pipe flows. A patented sand filter was developed in the laboratory and is undergoing field trials (27,28).

Multiphase Flow Loop

A multiphase/multicomponent 5 cm diameter pipeline flow loop 100 m long is being commissioned and will be used for a variety of investigations including wax deposition studies, emulsion pipelining, polymer flow modifiers, multiphase composition and flow measurement (figure 26). A jacketed glycol heating/cooling system controls temperature accurately over a wide temperature range.



◀ **Figure 25.** The Research Council solids control test cell is used to investigate the performance of different solids control devices.



◀ **Figure 26.** Multiphase/multicomponent 5 cm diameter, 100 m long pipeline flow loop.

Composition and Flow Measurement

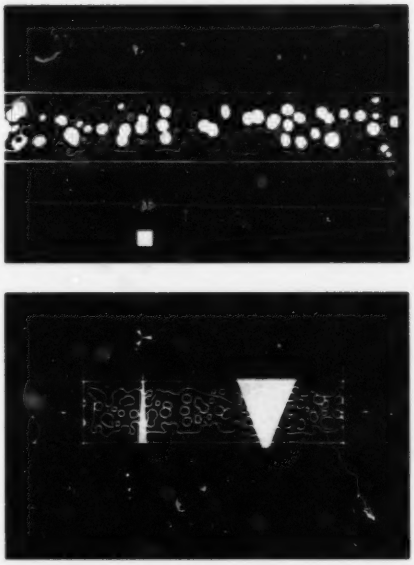
A proprietary multicomponent composition and flow meter using gamma and neutron gauges is being calibrated and evaluated (29). Other on-line measurement techniques are also being evaluated (figure 27).

Downhole Corrosion

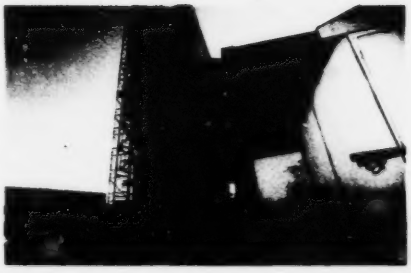
Corrosion studies focus on downhole environments. A recent study focused on the corrosion of carbon steel by carbon dioxide, a corrodent present in almost all production fluids. Low pH and ambient temperatures exacerbate CO_2 corrosion problems. Dissolved CO_2 significantly enhances the corrosion of steel over a wide pH range of 4 to 10. Researchers determined the CO_2 corrosion mechanism on the basis of electrochemical measurements, electrochemical modelling, time dependent speciation of CO_2 in water and identification of surface films (30).

Pump Simulator

A multiphase downhole pump simulator is being commissioned for pump performance studies using variable oil-water-gas-sand compositions, variable reservoir pressures and temperature, adjustable pumping speeds, and stroke lengths. The work is directed towards performance characterization of commercial pumps, developing new pumping systems and operating strategies, and investigating wear and corrosion problems.



◀ **Figure 27.** Different radiation techniques for on-line measurement of composition and flow rates of multicomponent mixtures are being investigated (top and bottom pictures).



◀ **Figure 28.** Pump and well bore simulator.

Support Services

The Analytical Services and Research Laboratory provides general analytical support for in-house research projects (figure 29). The laboratory conducts special investigations for industry in areas not available from commercial laboratories. The laboratory is equipped with up-to-date equipment to analyze complex production samples containing oil, water, solids and gas mixtures including UV-visible, X-ray fluorescence and diffraction, infrared, atomic absorption, gas and liquid chromatography, simulated and true distillation. Special research projects are carried out. Supercritical fluid chromatography utilizing supercritical CO_2 as the mobile phase allows separation of oil and bitumen fractions into either component types or individual compounds using packed or capillary columns (31). Asphaltene flocculation studies are conducted to evaluate the relative compatibility of various solvents with bitumen (32). A new chromatographic method for determining aromatics in diesel fuel was evaluated (33).

Sample Bank

With funding from the Alberta Oil Sands Technology and Research Authority (AOSTRA), the Alberta Research Council established the Oil Sands Sample Bank in 1978. The functions of the Sample Bank are to provide researchers in Alberta and worldwide with representative samples of oil sand, bitumen, heavy oil and related materials from Canadian deposits (figure 30). The Sample Bank also assesses analytical methods (34) and provides information on the physicochemical properties of samples. Studies are conducted on the processability of oil sands (35) and on the aging through oxidation of heavy minerals; notably pyrite. The Sample Bank works with the Alberta Committee on Oil Sands Analyses (ACOSA) to assess and improve the quality of routine analytical methods. Other activities include design of sampling and analytical procedures for extraction and upgrading pilot plants.

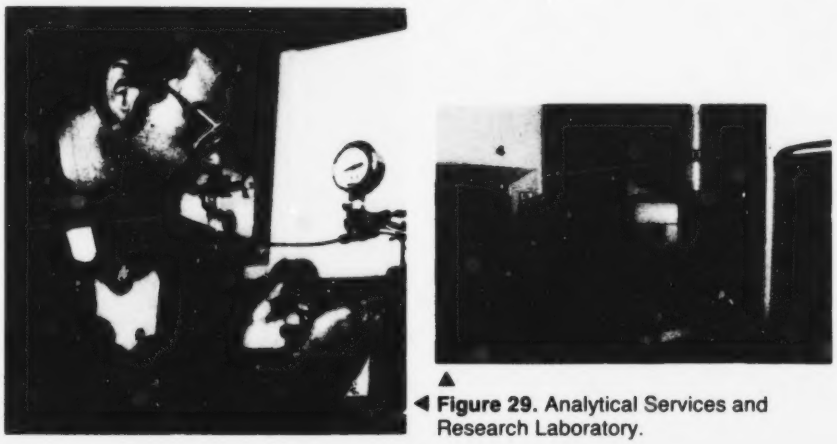


Figure 29. Analytical Services and Research Laboratory.

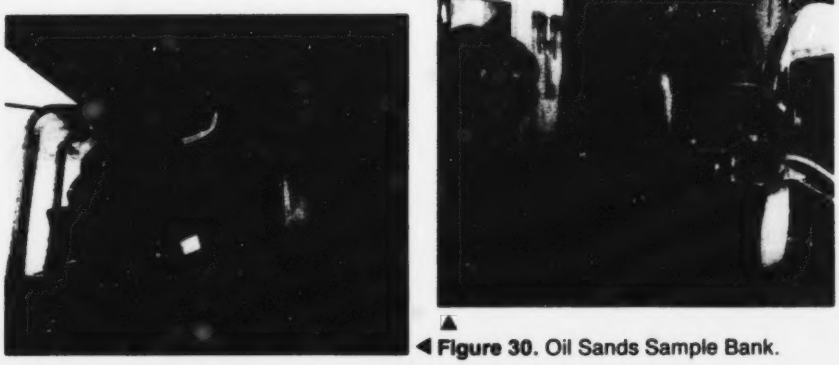


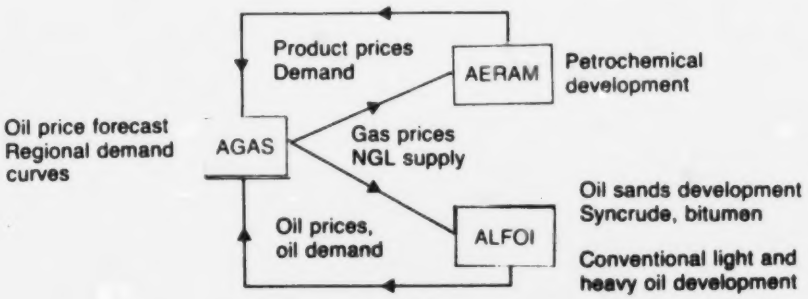
Figure 30. Oil Sands Sample Bank.

Technical and Economic Evaluations

Since 1975 the technical and economic evaluation group has developed a suite of three, large-scale linear programming models for energy policy planning purposes (figure 31). ALFOI is an oil supply model projecting on a yearly basis the production of liquid fuels in Canada for the next 20 years using specified price-demand trajectories (36). AGAS is a natural gas trade model for North America; both Canadian and U.S. supplies and demands are regionalized and modelled explicitly (37). AERAM is a detailed petrochemical model for Canada; both Alberta and eastern Canadian petrochemical complexes are modelled (38). Each of these models seeks a production schedule which maximizes the present value to the industry for a given price projection and a demand trajectory. Linked together, the three models provide a complete and consistent means of analyzing hydrocarbon and petrochemical developments in Canada.

A number of general purpose and specialized models have also been developed to facilitate process economic evaluations and sensitivity studies. PRICE is a general purpose costing package from McGraw Hill to generate factor capital cost estimates. DCF is a general purpose discounted cash flow analysis model which calculates required selling prices or internal rate of return. WOILP is a world oil price model developed in-house. Based on estimates of supply/demand elasticities and perception of OPEC objectives, the model generates price projections for scenario analyses. AFOM is an optimization model developed in-house to evaluate the economic viability of commercial in situ projects (39). Economic and field development constraints can be imposed.

These models are used to assess the technical and economic potential of novel energy processes, to perform sensitivity studies comparing alternative processes and strategies, and to determine the viability and appropriate timing of new in situ heavy oil extraction plants using steam, hot water, additives and foams.



▲ **Figure 31. Suite of Research Council models.**

Partners in Research

The Alberta Research Council works with industry, government, universities and other research centers in a variety of ways.

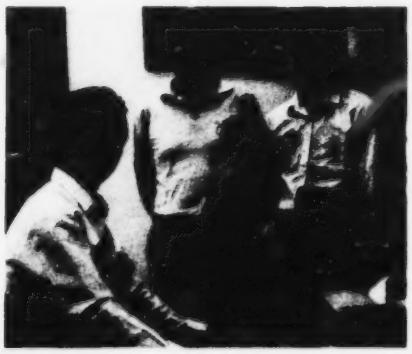
Contract research is conducted for industry on a fully funded confidential basis. In special cases, joint ventures are carried out with industry on a cost shared basis. Projects are one to two years in duration. A prerequisite is that the Research Council and the company have complementary skills which are needed for the technical and commercial success of the project. The seismic project for monitoring miscible fronts is an example of such a Joint Venture (11). Multidisciplinary teams can be formed to meet the particular needs of individual projects. Projects are carried out in close liaison with other groups within the Research Council most notably Advanced Materials, Advanced Technologies (Expert Systems and Artificial Intelligence), and Biotechnology.

Contract research and a cost shared program are carried out with Alberta Oil Sands Technology and Research Authority (AOSTRA). The cost shared program focuses on generic research supporting field pilots. Companies can participate in the program by paying an annual membership fee (2 percent of total program cost), which provides direct access to the research conducted at the Research Council (figure 32 top) as well as commercial use rights to the project technology. The geology program is a cost shared program among the Research Council, AOSTRA and Alberta Energy. The Sample Bank and Library and Information Service are operated by the Research Council with full funding from AOSTRA.

We interact with universities through joint supervision of graduate students, faculty members who spend their sabbatical leave at the Alberta Research Council and adjunct faculty appointments for Research Council staff. The Research Council also participates in the AOSTRA University Program and the Stanford University Petroleum Recovery Institute reservoir modelling program.

The Alberta Research Council collaborates with other regional and national centres to ensure complementarity of work and skills. Examples are collaboration with the Centre for Frontier Engineering Research (Edmonton) on downhole wear and corrosion problems; the Computer Modelling Group (Calgary) on developing large-scale reservoir simulators; the Petroleum Recovery Institute (Calgary) on laboratory methods for studying enhanced recovery of conventional oil; the Saskatchewan Research Council on pipelining and multiphase flow; the National Research Council on novel extraction techniques, with the Canadian Centre for Mining and Mineral Research on colloids and emulsions, and with the Canadian Energy Research Institute (Calgary) on economic modelling.

Recent foreign market opportunities for Alberta technology have stimulated staff exchanges with China (figure 32 bottom). A contract to assist in the development of an Oil Sands project in Indonesia is under negotiation.



◀ **Figure 32.** Visiting scientists from B.P. (U.K.) working on relative permeability (top), from the University of Alberta (right, center) working on mineralogy and from RIPED China working on foam displacement (bottom) and mathematical modelling (left).

Conclusion

Over the last 16 years the Alberta Research Council's research program in oil sand and hydrocarbon recovery has focused on in situ recovery of oil. Technology packages have been developed for steam based processes which have been transferred for field trials. The objectives of the current multidisciplinary program is to develop a better understanding of these processes, to investigate ways of making them more economical and more productive, and to guide, support and optimize field operations. Having the scientific and technical expertise and infrastructure the Research Council can provide cost effective research to clients from industry and government in a variety of ways including contracts, joint ventures and multiclient studies. The Council can also act as the research arm of clients who choose not to conduct their own in-house research.

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